Characterizing Embodied Interaction in First and Third Person Perspective Viewpoints

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Abstract

Third Person Perspective (3PP) viewpoints have the potential to expand how one perceives and acts in a virtual environment. They offer increased awareness of the posture and of the surrounding of the virtual body as compared to First Person Perspective (1PP). But from another standpoint, 3PP can be considered as less effective for inducing a strong sense of embodiment into a virtual body. Following an experimental paradigm based on full body motion capture and immersive interaction, this study investigates the effect of perspective and of visuomotor synchrony on the sense of embodiment. It provides evidence supporting a high sense of embodiment in both 1PP and 3PP during engaging motor tasks, as well as guidelines for choosing the optimal perspective depending on location of targets.

Keywords: Virtual Reality, Embodied Interaction, Embodiment, Third Person Perspective.

Index Terms: H.1.2 [Models and Principles]: User/Machine Systems—Human factors I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality J.4 [Social and Behavioral Sciences]: Psychology—

1 Introduction

The sense of embodiment into an avatar is constitutive of the sense of presence in virtual reality (VR) and affects the way one interacts with virtual elements [9]. Cognitive science research suggest that the sense of embodiment rises as a product of the combination of three components, namely (i) the sense of agency, i.e. feeling of motor control over the virtual body; (ii) the sense of body ownership, i.e. feeling that the virtual body is one's own body; and (iii) self-location, i.e. the experienced location of the self. From a more practical standpoint, changing the perspective from first (1PP) to third person perspective (3PP) allows taking a new and potentially more informative point of view within a VR application (such as for training [3, 17, 4]). The problem is that 3PP breaks the natural condition in which subjects experience self-location with respect to their real bodies, and might consequently lower the sense of embodiment and the sense of presence.

Although the exact impact of perspective change on the sense of embodiment is still subject to investigation in fundamental cognitive science research [12, 14], recent studies provide us with elements of answers. In two experiments where visuotactile synchrony and perspective were manipulated [21, 16], authors show evidence of a strong influence of perspective on the sense of ownership of a virtual body, higher than the influence of visuotactile synchrony. The influence of perspective on embodiment during immersive full-body realistic interaction with objects is however not known.

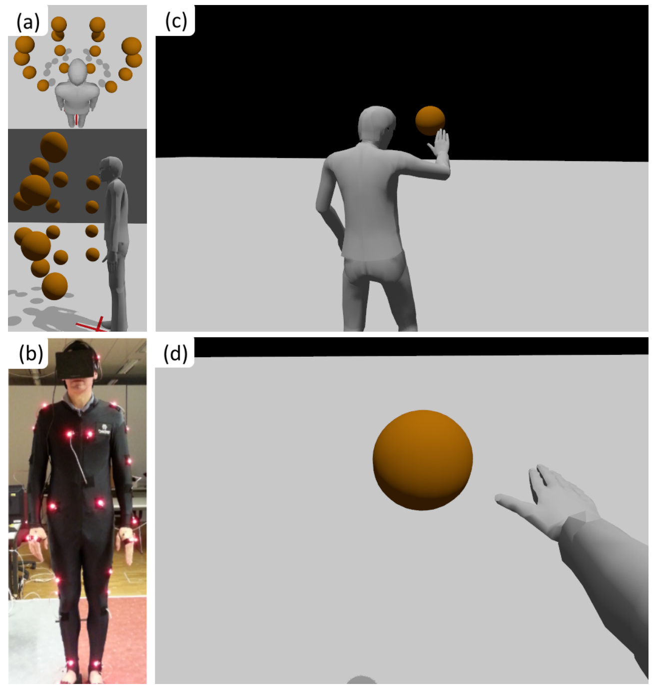

Figure 1: Experimental setup. (a) Location of targets that subjects have to reach; (b) Motion tracking suit and immersion equipment; (c-d) Illustration of what subjects saw during the reaching task in 3PP and 1PP respectively.

Using an experimental paradigm based on full-body visuomotor synchronous mapping (the coherent replication of one's real body by a virtual body), we studied the effect of perspective (1PP vs. 3PP) and synchrony (movement delay) on the sense of embodiment as well as on the performance in a reaching task. Subjective reports of the sense of agency, sense of body ownership and self-location were used to estimate the sense of embodiment [9]. This allowed studying how full body visuomotor synchrony is effective in inducing embodiment with respect to perspective, and measuring the performance trade-offs for performing a task with a 3PP viewpoint.

The next section introduces the context on current research on embodiment in VR, as well as related work evaluating the benefits of 3PP. Section 3 presents the design of the experiment, and Sections 4 and 5 describe the analysis of data and the obtained results. In Section 6 we discuss these results, further develop connections with other studies and present an overview of our findings.

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2 Related Work

A classical experiment that demonstrates how one may feel ownership over an artificial extracorporeal object is the rubber hand illusion (RHI) [2]. In this experiment the real hand is obstructed from the visual field and a fake rubber hand is placed instead. When both real and rubber hands are synchronously stroked by a brush, subjects might experience the feeling that the rubber hand is their hand, and react to threats directed to the dummy hand [1]. Additionally, when asked to use the opposite hand to point to where the hidden hand is, subjects tend to wrongly localize the position towards the rubber hand. This measurement is better known as the proprioceptive drift, and is generally positively correlated with the reported intensity of ownership illusion [2]. The sense of ownership and proprioceptive drift are not induced when the delivered touch is asynchronous or at incongruent positions. It has also not been found when the fake hand is placed in an incongruent orientation with respect to the real hand, or if it is replaced with an object that does not resemble a hand [22]. Passive and active synchronous movements are also shown to elicit this phenomenon [23, 24, 8], possibly stronger for active movement [23]. The RHI has been replicated in VR and is known as the virtual hand illusion. It has been induced by visuotactile [20], as well as by visuomotor synchrony [18, 25].

A full-body analogue of the RHI has been studied using a setup based on a stereoscopic camera watching a subject from the back and transmitting the image of the body in a third person perspective to the subject wearing Head Mounted Display (HMD). On the one hand, a synchronous visuotactile stimulation delivered to the subject's chest and to the space below the stereoscopic camera was shown to elicit the sensation of being located on the viewpoint position, i.e. behind the actual body [6]. On the other hand, a synchronous visuotactile stimulation delivered to the subject's back was shown to rather provoke the sensation of embodying the distant body seen from the 3PP [12]. More specifically, subjects felt to be located where they saw the virtual body to be, and reported feeling ownership of the seen body. A follow up experiment replicated this with an alternative self-location drift measurement [11], and authors concluded that self-location drifted towards the place where the visuotactile stimulus was shown (either at the camera or at the seen body).

3PP is often employed in non-immersive virtual environments such as video games to increase awareness of the environment and threats to the player, thus overcoming field of view limitations of 1PP. In VR, the usage of orthogonal third person viewpoints has been explored and was for instance recommended to help setting the posture of a motion controlled virtual body [3]. The use of 3PP is also recommended to compensate for the compression of distance perception inherent to immersion systems such as large stereoscopic projection. This was demonstrated in a VR basketball application in which motor behavior were closer to reality in 3PP than in 1PP (speed at moment of release closer to real throw than in 1PP) [4]. For HMD, it was shown that a short training is sufficient for subjects to perform distance estimation in 1PP and 3PP with similar precision [17]. The question is therefore to know if these benefits of 3PP can be exploited without detrimental consequences on the immersion and the ability to embody an avatar.

3 Experiment Design

For this experiment, subjects wearing motion capture sensors and HMD (Figure 1b) were asked to touch virtual targets that popped-up at a set of predefined positions (on a shuffled order) within a hemisphere aligned with their virtual body (Figure 1a). This task was repeated for combinations of 3PP and 1PP (Figures 1c and 1d respectively) in synchronous and asynchronous visuomotor condition (1 second of delay). The experiment followed a within subject factorial design with the factors perspective (1PP/3PP) and synchrony (Sync/Async). Each factor combination was repeated 3 times, for a total of 12 blocks per subject. A subjects went through all the blocks of a perspective condition before switching to the other. Perspective presentation order was counterbalanced per subject, while the presentation order of the 6 blocks within each perspective condition was randomized.

3.1 Procedure

Each block consisted of 90 seconds of VR exposure during which subjects were standing and performed several reaching movements using any part of their body. After each block, subjects were guided to a desktop computer and were asked to remove the HMD and to fill-in the questionnaire using a regular mouse. Questions were presented in white over a black background. The subjects were allowed to sit and rest between blocks, and were informed about how many blocks were left.

The questionnaire was adapted from [12, 23] to estimate subjective sense of agency (Q1), sense of body ownership (Q2) and self-location (Q3). Q4 asked whether the subject felt to have two bodies (control). A Visual Analogue Scale (VAS) was used to record answers ranging from "disagree" to "agree" (100%). The questionnaire is presented in Table 1.

Questions			**Asynchrounous**		**Synchronous**			**1PP**		**3PP**		
During the last session there were times when...		Group	Median	IQR	Median	IQR	p	Median	IQR	Median	IQR	p
Q1. ...it felt like I was in control of the body I was seeing	**(Agency) Agc**	**All**	39.5	40.4	95.9	8.4	**0.000** *	85.5	52.6	69.0	58.6	0.221
		1->3PP	53.0	56.4	94.8	7.6	**0.001** *	89.0	34.9	92.3	53.6	0.860
		3->1PP	37.5	28.7	97.9	9.6	**0.000** *	78.6	59.2	71.3	58.6	0.148
Q2. ...it felt that the virtual body was my own body	**(Body Ownership) BOwn**	**All**	45.6	40.4	89.8	19.9	**0.000** *	76.9	44.5	65.9	52.2	0.914
		1->3PP	55.2	67.4	85.6	29.7	**0.000** *	76.9	32.4	65.6	55.1	0.375
		3->1PP	40.5	28.6	92.9	10.8	**0.000** *	75.8	54.3	67.0	45.0	0.222
Q3. ...it felt as if my body was located where I saw the virtual body to be	**(Self-location) SLoc**	**All**	50.0	34.0	91.6	22.9	**0.000** *	82.8	40.1	66.7	42.2	0.883
		1->3PP	54.1	49.0	88.7	25.6	**0.003** *	83.8	30.8	63.6	46.2	0.782
		3->1PP	44.4	24.2	92.8	17.7	**0.000** *	78.6	49.4	67.9	40.8	0.755
Q4. ...it felt as if I had more than one body	**(More bodies)**	**All**	66.4	29.4	33.2	58.1	**0.017** *	52.0	58.4	58.4	46.0	0.197
		1->3PP	73.0	38.9	40.9	59.2	0.403	60.5	52.8	72.9	54.7	0.433
		3->1PP	62.3	18.7	23.9	32.1	**0.030** *	36.6	56.1	46.9	33.4	0.193

Table 1: Questions (left) and questionnaire results (right). Answers were given in a visual analog scale (VAS) ranging from 0 to 100. Median, interquartile (IQR) and significance (Wilcoxon Signed-Ranks test) for synchrony and perspective factors are presented. Results per groups (perspective presentation order: 1PP- 3PP and 3PP- 1PP) are also shown.

3.2 Recruiting

In order to minimize variations on the motion capture stability and visual experience over subjects, we established four recruitment criteria: male gender; ability to focus on infinity without glasses or using corrective lenses bundled with Oculus HMD; height between 170 cm and 185 cm; body mass index (BMI) between 18 and 23.

A total of 16 subjects participated to this study (ages from 21 to 31, mean of 26, all right handed). They were recruited through an online call in the university and were paid 20 CHF per hour of their time. The experiment took between 70 to 110 minutes, depending on the setup time (calibration and adjustments). The subjects signed a consent form and were informed about the purposes of the experiment, as well as the possibility to abandon the experiment at any moment.

3.3 Measurements

The dependent variables are; reported sense of *Agency* (Agc), sense of *Body Ownership* (BOwn), *Self-Location* (SLoc), *Mean Time* to reach (MT), and *End Effector* choice (EE). Agc, BOwn and SLoc were measured through questions Q1, Q2 and Q3 respectively.

MT represents the mean time each subject took to reach a specific target out of the 16 possible targets (Figure 1a), and is relevant only for the synchronous condition. For analysis, it is split in two stages, the early one accounts mostly for visual search and movement initiation (MTS1) and the late one accounts for movement completion and target hit (MTS2). MTS2 is measured from the last cross of 50% of the distance between initial position of the limb and target position (MTS1 is computed as MT - MTS2). As the typical velocity profile of a reaching movement tends to be symmetrical and to resemble a normal distribution [19], this splitting criteria allows dividing the movement where it is more likely to reach its maximum velocity. This is also where it is less likely that information expected to be part of MTS1 would affect MTS2, and vice versa.

Finally, end effector preference ratio (EE) describes the preferred limb used for selection per given target. It is measured as the proportion of times the subject used a given limb over the total number of reachings he performed for that target.

3.4 Hypotheses

We identified five hypothesis that our experimental manipulation will allow to investigate.

H1: The synchrony of avatar movement influences the sense of embodiment and each of its component : Agc (H1.1), BOwn (H1.2) and SLoc (H1.3). This will indicate if full body visuomotor synchrony is a factor influencing the components of embodiment.

H2: The perspective factor influences the sense of embodiment and each of its component : Agc (H2.1), BOwn (H2.2) and SLoc (H2.3). This will indicate if perspective is a factor influencing the components of embodiment.

H3: Agency is an enabling factor for body ownership and self-location. Observing a correlation between the reported Agc with BOwn (H3.1) and SLoc (H3.2) will indicate if the sense of agency for the avatars movement is linked to other components of embodiment.

H4: Time to reach targets is influenced by perspective. In particular, we expect that 3PP will present shorter MT by reducing required visual search time (H4.1). More specifically, we expect MTS1 to be smaller for 3PP (H4.2), and MTS2 to be equivalent across perspective change (H4.3). This analysis will highlight locations of targets showing an advantage for 3PP, or conversely. We do not consider the Async trials in this question as its effect is inherently negative.

H5: Subjects can accomplish the task in a similar manner across perspective conditions. This will be assessed through variations of preferred end effector (EE) per target position across perspective.

3.5 Implementation

Equipment– A Phasespace Impulse X2 was used for motion capture, 10 cameras were used to track 38 markers attached to an elastic suit and to the HMD. Data were acquired at a frequency of 60Hz. An Oculus DK1 was used to display images at a resolution of 640 x 800 pixels per eye. Its inertial sensors were used to obtain instantaneous head orientation, which was corrected for drift around the vertical axis using the attached optical markers. Figure 1b shows a subject wearing the suit and HMD. The integrated HMD sensors were used because they offer effective prediction as well as shorter latency.

Perspectives– 1PP: markers attached to the Oculus were used to place the virtual camera as close as possible to the subject eyes position. Rotation and translation were computed from those markers and from the inertial sensors in the Oculus. 3PP: the only difference with 1PP was an offset of 120cm backwards (behind the avatar). Translation and rotation were centered at that point. Figure 1c and 1d presents screen captures for 3PP and 1PP respectively.

Synchrony– Sync: motion capture and camera translation and rotation in real time. Async: 1 second delay of motion capture and cameras translation. Camera rotations were kept in real time to prevent cybersickness.

Posture reconstruction– Full body motion capture was performed in real time. To account for body size variability, a calibration step was performed based on a standard posture (T-stance) that subjects were asked to perform. Lower and upper body of the virtual body were adjusted in scale, followed by arm adjustments. Finally, orientations of limbs, trunk and head were adjusted to closely match those of the subjects. A new iteration was performed if required. This calibration allowed for a close match of real and virtual bodies, and known limitations (e.g. incorrect arm and forearm proportions) were minimal thanks to the subjects' recruiting criteria. To animate the virtual body we used an in-house analytic IK implementation which reinforces co-location of tracked markers and end effectors positions [15]. Fingers were not animated and were kept in a neutral pose. Discontinuities of posture reconstruction could occasionally occur during motion capture if the position of a marker became unknown – limitations of the optical tracking equipment – and we limited the visual consequence to the drop of one animation frame (less continuous movement). This occurred rarely during our experiment, only in case of very fast reaching movements (system could momentarily loose track of the marker) or self-occlusion.

Task– Target reaching with 16 predefined positions. Targets were spread over the surface of a sphere segment of 80cm radius, centered at $x = 0$, $y = 1.2m$ and $z = 0$ (with positive y pointing up). Targets were represented as spheres of $10cm$ radius. After each reach, the subject had to return beyond a line in the floor, oriented along the lateral axis. The next target appeared 1 second after assuming the aforementioned position.

Virtual environment– The subject stood over a flat plane, in which we avoided presentation of any potential spatial cues. A unique neutral and not textured virtual body was used for all subjects.

4 Analysis

Questionnaire analysis for H1 and H2 was carried out using Wilcoxon Signed-Ranks Test, for which data were paired per subject across the combination of conditions (1PP/3PP and Sync/Async). Spearman correlation was computed between variables for H3.

Only the data in the Sync condition was used for performance analysis of MT (H4). Our analysis includes time to reach responses (MT, MTS1 and MTS2), and was carried out with paired samples t-test. More specifically, we compare difference on MT, MTS1 and MTS2 between perspectives for each of the 16 possible targets. Outliers were defined based on interquartile distance (i.e.

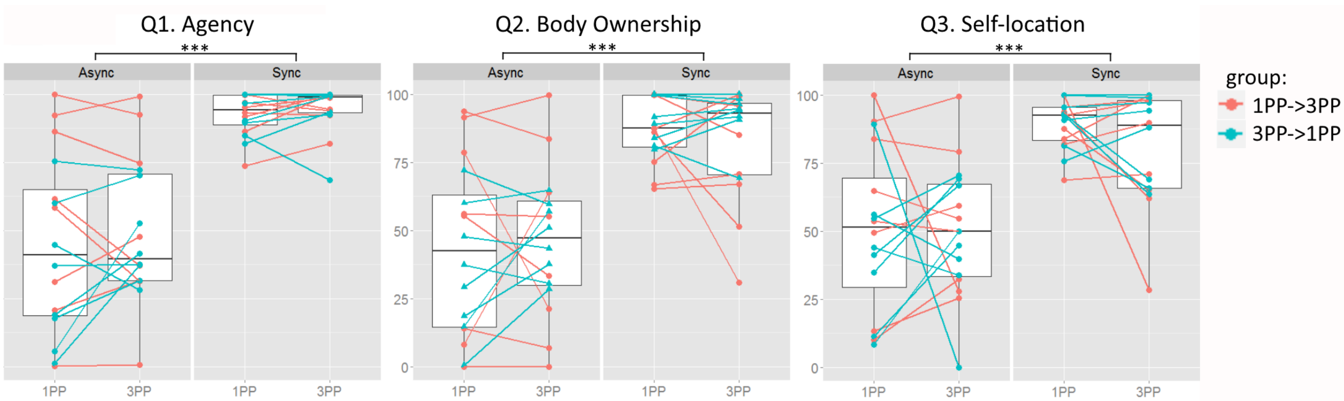

Figure 2: Boxplots of reported sense of agency (Q1), sense of body ownership (Q2) and self-location (Q3). Lines represent per subject change in response across perspective; *** means significance with p<0.001.

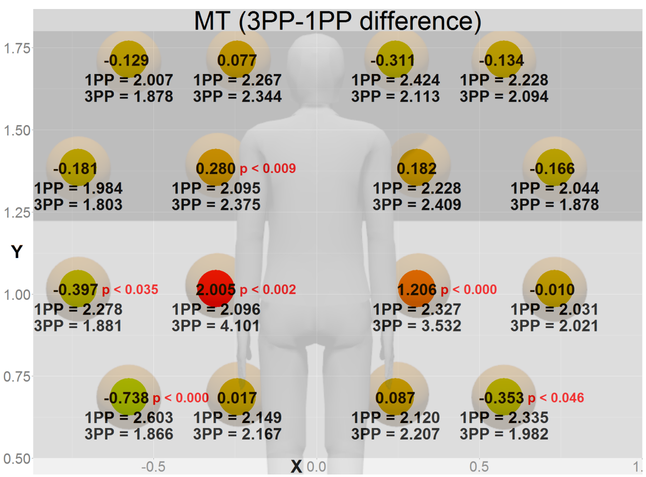

Figure 3: Mean time difference for MT. The redder, the bigger the advantage of 1PP; the greener, the bigger the advantage of 3PP; p-values in red indicate significant differences in a two-sided paired t-test for that specific target.

less than quartile of $25\% - 1.5 * IQR$ or greater than quartile of $75\% + 1.5 * IQR$) per perspective × target position combination. Targets that were selected using the trunk or the head were very few, and were removed to prevent bias. Therefore, from the total of 1760 trials, 1627 were kept for analysis. If a data point for a given perspective and target position combination was missing for a subject (i.e. no selection performed for that specific combination), its pair was also removed from the analysis.

The same subset of trials was used for EE choice (H5). One-sided paired t-test was used to compare perspectives for superior and inferior limbs, as well as left and right sides of the body for each target position.

5 Results

Differences for synchrony are significant for Agc, BOwn and SLoc (all $p<0.001$, Figure 2), confirming H1.1, H1.2 and H1.3. Although Q4 was meant to be a control question, it also presents a significant difference ($p<0.02$), but much weaker. Perspective only has significant effect for Q4 when considering Sync condition alone ($p<0.03$). Differences for perspective are not significant for Agc, BOwn nor SLoc (Figure 2), thus failing to reject equality for H2.1, H2.2 and H2.3. Agc responses are positively correlated with BOwn and SLoc, supporting H3.1 and H3.2 (all $p<0.01$). Table 1 shows the Median, interquartile and p-values for the whole sample analysis, as well as for groups (2 groups, those who started with 1PP and those who started with 3PP). The responses to all questions except Q4 agree when statistics for unbalanced groups are taken, which demonstrates no order effect for relevant measurements.

MT shows no global advantage for any specific perspective, but selection of targets surrounding the avatar show an advantage for 3PP, and selection of targets that may be occluded by the virtual body show an advantage for 1PP. Only 6 out of the 16 (37%) target positions presented statistically significant difference of MT between conditions (Figure 3). MTS1 follows the tendency of MT, with significant differences for 10 out of 16 target positions (62%). MTS1 reveals a clearer advantage for 3PP for targets that are not subject to occlusion. On the other hand, targets that are likely to be occluded presented the biggest differences of MT and MTS1. H4.1 and H4.2 are supported when visual occlusion is unlikely, but rejected otherwise. Nonetheless, MTS2 shows a clear disadvantage for 3PP as 8 out of 16 target positions presented statistically significant differences supporting 1PP (50%). In addition, only 2 out of 16 targets presented an advantage for the mean of 3PP as compared to 1PP in MTS2. Thus, providing evidence to reject H4.3. Figure 4 reports MTS1, MTS2 and their differences for each perspective and target combination.

Proportions of end effectors (EE) used for reaching are shown in Figure 5. They are similar when considering distribution for superior and inferior limbs, the difference being significant for only one target. However, lateralization seems to be unbalanced in 1PP, presumably due to handedness (subjects were all right-handed). This lateral distribution asymmetry does not seem to be present in 3PP. Laterality was significantly different for three targets located at the lower left of the virtual body. Thus, H5 is confirmed when considering superior and inferior limbs, but not entirely when considering right/left sides.

6 Discussion and Conclusion

The subjective reports of all three components of embodiment show a significant impact of visuomotor synchrony on body ownership and self-location. This is in line with experiments using full-body visuomotor synchrony in virtual mirror paradigms that elicit a high sense of ownership [7]. Other experiments comparing the influence of visuomotor and visuotactile congruency on body ownership also demonstrated a strong influence of visuomotor synchrony on multiple measures of embodiment [10].

Data also show that, in the context of our full-body interaction and reaching task, perspective differences (1PP vs. 3PP) did not

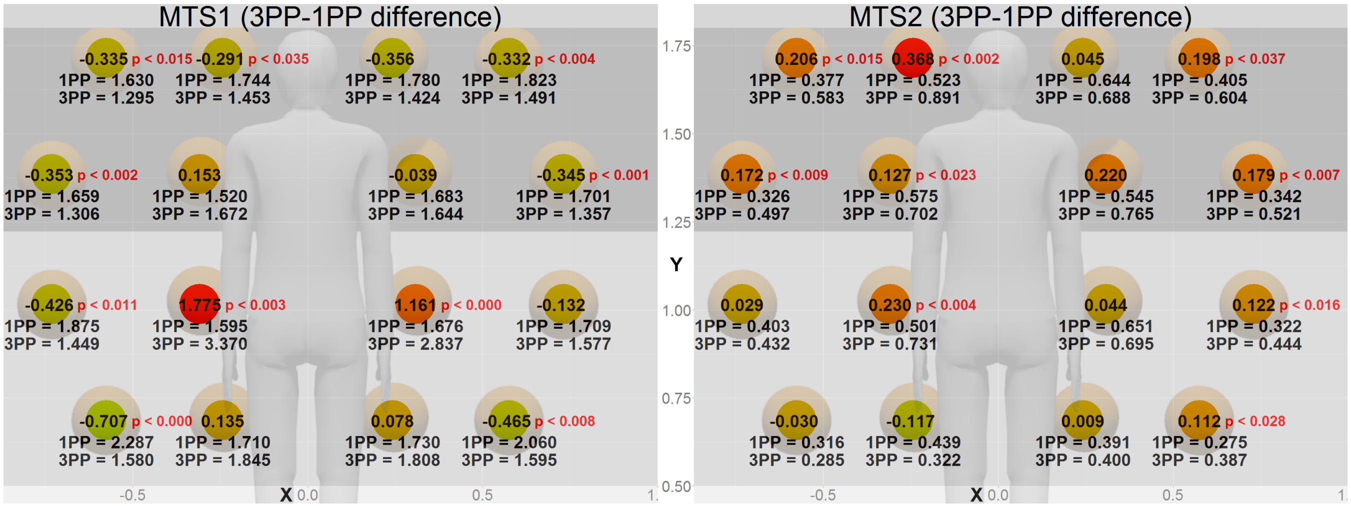

Figure 4: Mean time difference for MTS1 and MTS2. The redder, the bigger the advantage of 1PP; the greener, the bigger the advantage of 3PP; p-values in red indicate significant difference in a two-sided paired t-test for that specific target.

influence the subjective evaluations of embodiment. This contrasts with some previous work where the perspective change was observed to influence ownership of a virtual body [21, 16, 13]. We suggest three possible interpretations for that. First, the difference between 1PP and 3PP could be present but our measures are not sensitive enough: the perspective effect could be compressed and no longer significant as compared to the effect size of visuomotor synchrony. A second interpretation is related to the active nature of our task which differs from the experimental paradigms of these studies. Our reaching task required a high level of involvement, a sustained cognitive load and potentially leaded to the mental state of *flow* [5] also observed for computer game, for which different perspectives are all compatible with high gaming engagement. Finally, we might face a ceiling effect of full-body visuomotor control as compared to the influence of perspective (as in a virtual hand illusion). Even though the sense of agency is decoupled from the sense of ownership in its neural basis [23], ownership may be strongly driven by agency when shape and proprioceptive congruency are present [24]. This is also partially supported by the positive correlation observed between the sense of agency and the reported body ownership and self-location.

Taken together, these results suggest that a 3PP can be used for immersive full-body reaching tasks and is compatible with a high level of embodiment into the virtual body. Only the differences in reaching behavior between 1PP and 3PP highlight some specific advantages according to the location of targets. The lower performance over the end of the movement (MTS2) for 3PP suggests a decrease in precision, most likely due to the reduction of targets angular size and depth cues (one may expect similar difference if smaller targets are used). On the other hand, the absolute difference between early and late stages of movement (MTS1 and MTS2) suggests a visual search advantage for 3PP, as long as the target is not occluded. To the opposite, the comparison of the use of body parts (choosing to use upper or lower end effectors) suggests that our subjects did not change the way they interact with the VE. They often used the feet for lower targets in both 1PP and 3PP, suggesting that they were comfortable in exploring the full control over the virtual body independently of perspective. Finally, as we observe a crossing of the dominant hand towards targets on the opposite side only in 1PP, we believe 3PP may be used to enforce the use of the non-dominant hand in specific applications, such as for cognitive and clinical applications (e.g. spatial neglect rehabilitation).

Additional research would be required to disentangle the interaction between subjective reports of embodiment and observed reaching behavior. A computational model of the sense of embodiment based on observations of behavior would in theory be able to provide automatic estimates of the user's level of embodiment by analyzing movement data. But our experiment does not show any direct link or correlation that would provide an obvious solution, suggesting the need for stronger methods such as Bayesian statistics. Similarly, more experimentation would be necessary to compare our results with reaching behavior in reality. Using appropriate perspectives could for instance compensate for the known limitations of VR for reaching [3], throwing [4] or other natural interaction movements. Evaluating the transfer of skill from VR training to the real situation would in turn provide information on the benefit of providing subjects with a feedback on their body and their surrounding (such as in 3PP).

In summary, our results contribute to the understanding of the interplay of the multiple components supporting embodiment and show that several factors (visuomotor congruency, visuotactile congruency or perspective) can have a positive impact on body ownership and embodiment depending on the tasks to perform and on the stimuli provided. In our case, in absence of tactile stimulation and in the context of action oriented tasks, visuomotor synchrony dominates over perspective. Under other circumstances, perspective can dominate over visuotactile congruency when the manipulation focuses on the contrast between the location of the touch and the change of perspective [21]. Understanding the cognitive mechanisms of embodiment is a fundamental challenge for the development of VR interaction and needs to be investigated further. It is precisely because VR allows controlling factors such as perspective and analyzing behavior in ecologically valid conditions (e.g. differences in timing of reaching movements) that it provides the necessary environment for conducting this cognitive neuroscience research.

Acknowledgements

We would like to thank the reviewers for their time and valuable opinion and suggestions. This research is supported by the SNF project (No. 140910).

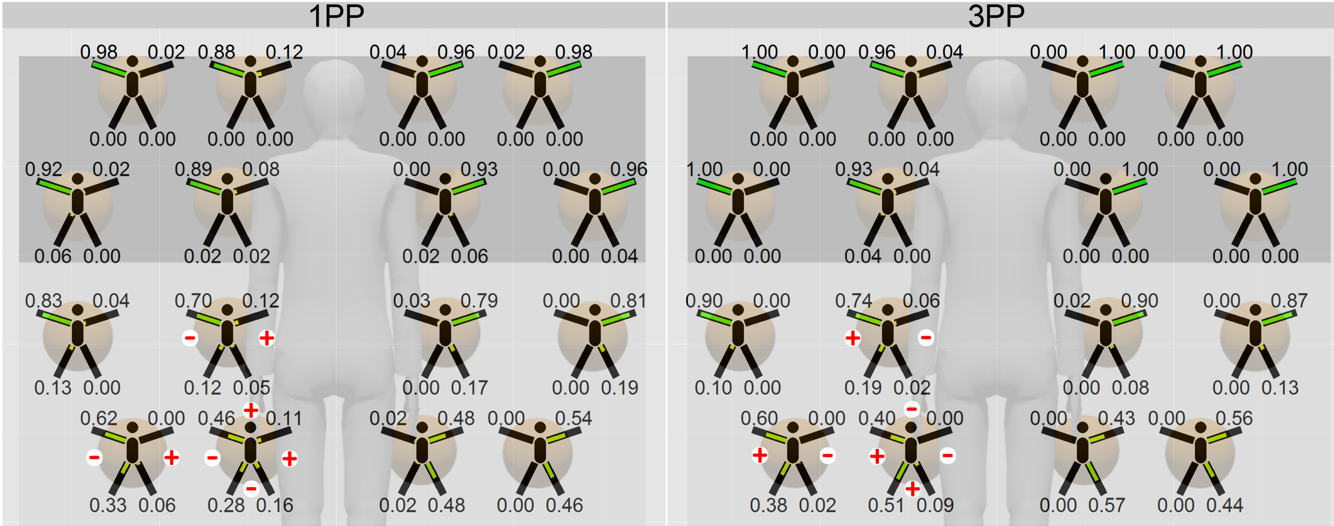

Figure 5: End effector (EE) of preference for each target for 1PP and 3PP. +/- indicates significant difference (increase/decrease) for inferior/superior limbs and/or left/right sides of the body (e.g + at the left of the target indicates increased usage of left EEs for that perspective). In 3PP laterality was enforced in contrast to handedness in 1PP.

References

[1] K. C. Armel and V. S. Ramachandran. Projecting sensations to external objects: evidence from skin conductance response. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 270(1523):1499–1506, 2003.

[2] M. Botvinick, J. Cohen, et al. Rubber hands 'feel' touch that eyes see. *Nature*, 391(6669), 1998.

[3] R. Boulic, D. Maupu, and D. Thalmann. On scaling strategies for the full-body postural control of virtual mannequins. *Interacting With Computers*, 21:11–25, 2009.

[4] A. Covaci, A.-H. Olivier, and F. Multon. Third person view and guidance for more natural motor behaviour in immersive basketball playing. In *Proceedings of the 20th ACM Symposium on Virtual Reality Software and Technology*, VRST '14, pages 55–64, New York, NY, USA, 2014. ACM.

[5] M. Csikszentmihalyi and M. Csikzentmihaly. *Flow: The psychology of optimal experience*, volume 41. HarperPerennial New York, 1991.

[6] H. H. Ehrsson. The experimental induction of Out-of-Body experiences. *Science*, 317(5841):1048–1048, 2007.

[7] M. González-Franco, D. Pérez-Marcos, B. Spanlang, and M. Slater. The contribution of real-time mirror reflections of motor actions on virtual body ownership in an immersive virtual environment. In *Virtual Reality Conference (VR), 2010 IEEE*, pages 111–114. IEEE, 2010.

[8] A. Kalckert and H. H. Ehrsson. Moving a rubber hand that feels like your own: a dissociation of ownership and agency. *Frontiers in human neuroscience*, 6, 2012.

[9] K. Kilteni, R. Groten, and M. Slater. The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments*, 21(4):373–387, 2012.

[10] E. Kokkinara and M. Slater. Measuring the effects through time of the influence of visuomotor and visuotactile synchronous stimulation on a virtual body ownership illusion. *Perception*, 43(1):43–58, 2014.

[11] B. Lenggenhager, M. Mouthon, and O. Blanke. Spatial aspects of bodily self-consciousness. *Consciousness and cognition*, 18(1):110–117, 2009.

[12] B. Lenggenhager, T. Tadi, T. Metzinger, and O. Blanke. Video ergo sum: manipulating bodily self-consciousness. *Science*, 317(5841):1096–1099, 2007.

[13] A. Maselli and M. Slater. The building blocks of the full body ownership illusion. *Frontiers in human neuroscience*, 7, 2013.

[14] K. Meyer, O. Blanke, H. H. Ehrsson, and V. Petkova. Commentary e-letter. science. *Science. Available at: http://www.sciencemag.org/content/317/5841/1048, Accessed: 2014-11-14*, 2008.

[15] E. Molla and R. Boulic. Singularity free parametrization of human limbs. In *Proceedings of the Motion on Games*, pages 165–174. ACM, 2013.

[16] V. I. Petkova, M. Khoshnevis, and H. H. Ehrsson. The perspective matters! multisensory integration in ego-centric reference frames determines full-body ownership. *Cognition*, 2:35, 2011.

[17] P. Salamin, T. Tadi, O. Blanke, F. Vexo, and D. Thalmann. Quantifying effects of exposure to the third and First-Person perspectives in Virtual-Reality-Based training. *Learning Technologies, IEEE Transactions on*, 3(3):272–276, 2010.

[18] M. V. Sanchez-Vives, B. Spanlang, A. Frisoli, M. Bergamasco, and M. Slater. Virtual hand illusion induced by visuomotor correlations. *PloS one*, 5(4):e10381, 2010.

[19] A. Sciutti, L. Demougeot, B. Berret, S. Toma, G. Sandini, C. Papaxanthis, and T. Pozzo. Visual gravity influences arm movement planning. *Journal of neurophysiology*, 107(12):3433–3445, 2012.

[20] M. Slater, D. Perez-Marcos, H. H. Ehrsson, and M. V. Sanchez-Vives. Towards a digital body: the virtual arm illusion. *Frontiers in human neuroscience*, 2, 2008.

[21] M. Slater, B. Spanlang, M. V. Sanchez-Vives, and O. Blanke. First person experience of body transfer in virtual reality. *PLoS ONE*, 5(5), 2010.

[22] M. Tsakiris and P. Haggard. The rubber hand illusion revisited: visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance*, 31(1):80, 2005.

[23] M. Tsakiris, M. R. Longo, and P. Haggard. Having a body versus moving your body: Neural signatures of agency and body-ownership. *Neuropsychologia*, 48(9), 2010.

[24] L. D. Walsh, G. L. Moseley, J. L. Taylor, and S. C. Gandevia. Proprioceptive signals contribute to the sense of body ownership. *The Journal of physiology*, 589(12):3009–3021, 2011.

[25] Y. Yuan and A. Steed. Is the rubber hand illusion induced by immersive virtual reality? In *Virtual Reality Conference (VR), 2010 IEEE*, pages 95–102. IEEE, 2010.